Development of a Calibrated Watershed Model, Potomac River Basin

A Cooperative Project between the U.S. Geological Survey (USGS), the Interstate Commission on the Potomac River Basin (ICPRB), the Maryland Department of the Environment (MDE), and the U.S. Environmental Protection Agency Chesapeake Bay Program Office (CBP)

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Project Description

Problem. Work performed by the National Water-Quality Assessment (NAWQA) Program Potomac River Basin study unit (1992-95) indicated that elevated concentrations of nutrients in surface and ground water in the basin often result from human activities such as manure and fertilizer application. A watershed model of the basin is needed to assess the effects of point and nonpoint nutrient and sediment sources on water quality in the Potomac River and its tributaries.

Objectives. The USGS is responsible for the following objectives: 1) compile necessary data for simulation of Potomac watershed processes, using the Hydrologic Simulation Program-FORTRAN (HSPF); 2) create necessary control files for HSPF simulation of the Potomac River Basin, following the framework developed by CBP for Phase 5 of the Chesapeake Bay Watershed Model (CBWM); 3) develop and implement innovative calibration procedures to improve HSPF model calibration; 4) calibrate an HSPF model for the Potomac River Basin; and 5) prepare reports on calibration and analysis of model results.

Benefits and relevance. The calibrated Potomac Watershed Model will allow resource managers to simulate the effects of land-use changes and best management practices on water quality and evaluate alternative approaches for correcting existing water-quality and water-quantity problems within the Potomac River Basin. The proposed study also meets several goals of the USGS Water Resources Division (WRD).

Approach and methods. The proposed study will involve the following tasks: 1) compilation of existing input data, development of model segmentation and network, processing of time-series data, and compilation of ancillary data and observational data for model calibration; 2) development of a model calibration strategy through implementation of existing software for general inversion and calibration of multi-parameter hydrological models; 3) calibration of hydrological and water-quality model (sediment and nutrients); 4) analysis of model results, including consideration of specific study questions; and 5) dissemination of calibrated model and preparation of final reports analyzing the model results.

Progress During Reporting Period

Hydrology Calibration

During the past three months, effort was focused on hydrological calibration; this portion of the study has been completed, although there will need to be a final check once final land use and an updated (1984 through 2002) hydroclimatological dataset are available. We had hoped to have this verification step completed, but are still waiting on final daily and hourly datasets (from University of Colorado and NOAA, respectively).

In general, the hydrology calibration is very robust (as will be discussed below), with values for the critical accuracy statistics (bias, efficiency, correlation, recession indices) generally meeting our target values across the modeled region (and independent of location or basin size of other characteristics). The Phase 5 model has a greater efficiency for daily discharge prediction at almost all of the 16 Phase 4.3 calibration stations.

In order to achieve the current calibration, Gary Shenk (CBP) developed a strategy for iteratively determining the best set of model parameters, constrained by our expectations and based on the expertise and understanding developed over hundreds of hours of manual calibration by several individuals. There are several reasons why an objective approach was favored. Minimum, maximum, and ranges of some parameter values were outside of published values; there was user (and hence, basin) variation in choices of what parameters to adjust (especially AGWETP and KVARY). The previous calibration demonstrated strongly variable amounts of surface runoff, which needs to be somewhat constrained to provide for a reasonable sediment simulation; ratios of parameters between land uses within a segment were not always adhered to; and ratios of expected parameters values (e.g., UZSN:LZSN) were unconstrained. Finally, it has been a goal of this effort since the start to use objective calibration approaches when possible (and both USGS and ICPRB continue to pursue application of PEST).

In this approach, a limited number of parameters are selected for modification (LE, LZSN, INFILT, IRC, AGWR, INTFW). Ratios for certain parameters (UZSN:LZSN) and monthly variation in other parameters are constrained, as are parameter ratios across land uses. Between iteration parameter adjustment is constrained to a reasonable range of values, and the relations between accuracy statistics and the direction and amount of parameter adjustment is based on the group experience and consensus (Table 1). Parameter definitions may be found in the documentation for HSPF (Bicknell, Imhoff, and others, 1996) with the exception of LAND_EVAP which multiplies PET for the land segment. The accuracy statistics are summarized in Table 2. Note that efficiency is not used as a basis for parameter adjustment.

Table 1. Rules for iterative parameter adjustment based on accuracy statistics.

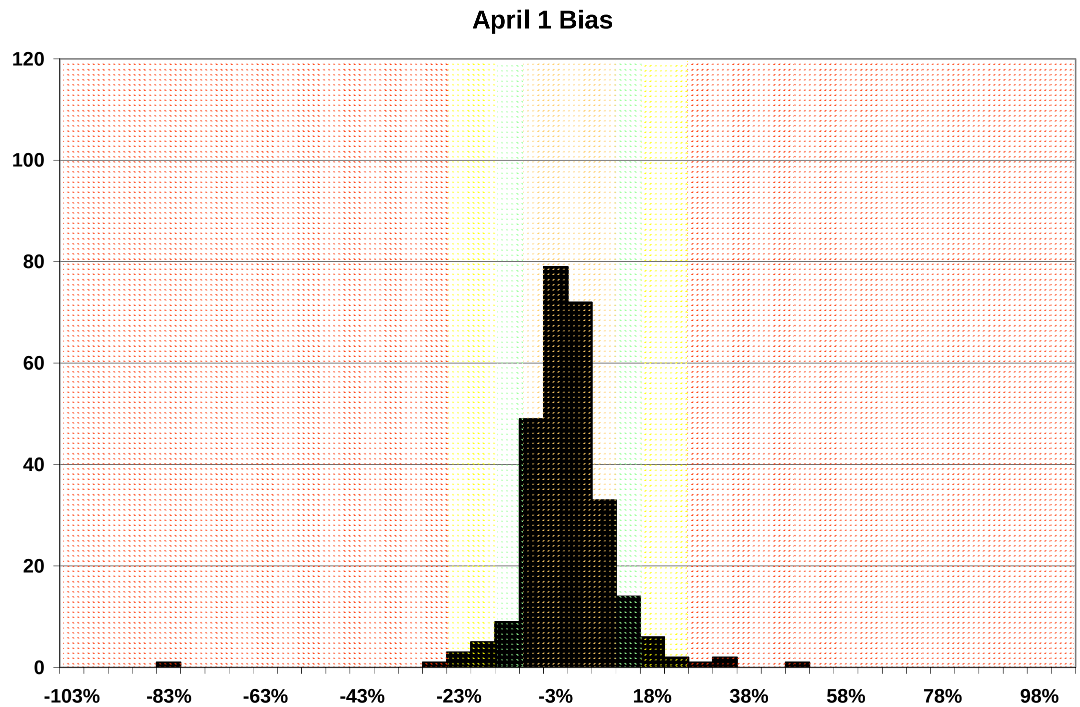
Parameter	**Statistic**	**Adjustment**
LAND_EVAP	Bias	LAND_EVAP = 2/(2 –Bias)
LZSN	Wstat/Sstat	LZSN = (3 – Sstat/Wstat)/2
INFILT	Bstat	INFILT = 1/Bstat
IRC	QaveRI	IRC = 2/(1 + QaveRI)
AGWR	BaveRI	AGWR = 2/(1 + BaveRI)
INTFW	Pbias/Vpbias	INTFW = 1 + (Pbias or Vpbias)/2

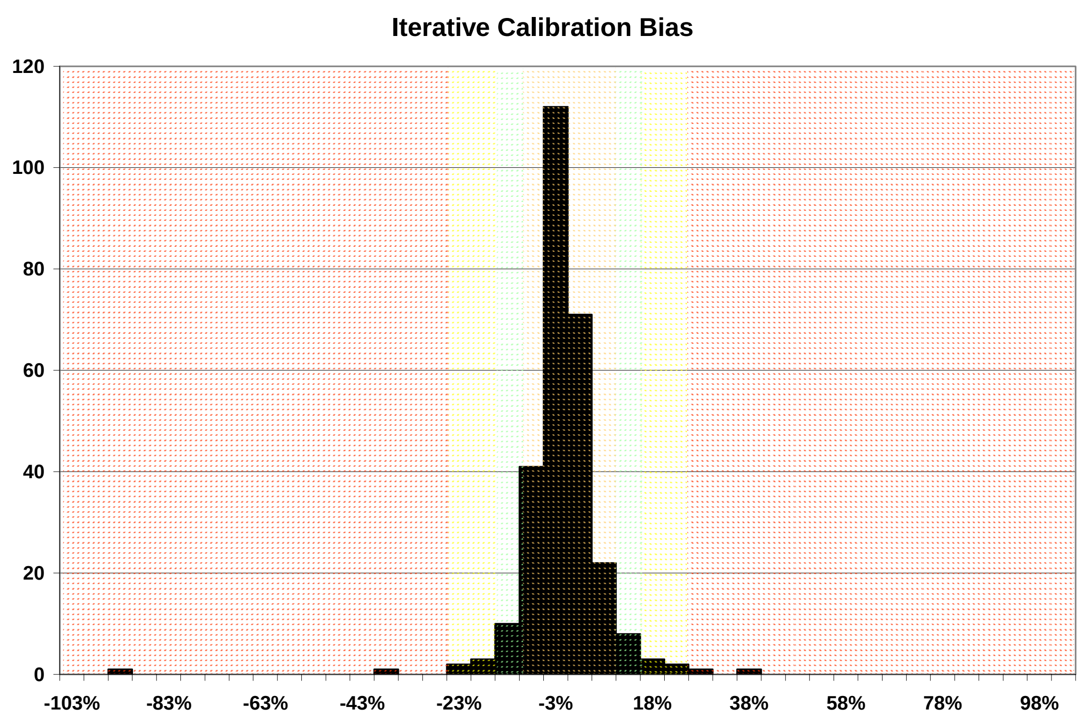
Following iterative parameter adjustment, the overall bias improved (figures below), and the efficiencies for most calibration stations improved. This was especially noticeable for small to moderate sized watersheds. Efficiencies were improved, even though model efficiency was not a statistic used to make parameter adjustments. This points to the strength of the procedure in providing objective improvements to model parameters controlling individual processes that improved overall model accuracy.

A number of tests were conducted to test the robustness of the model parameters. Different initial values, parameter adjustment rules, and other variations were examined for their impact on the iterative calibration and final parameter values obtained. None of these tests yielded significantly different parameter sets, demonstrating the robustness of the method and final parameter values.

Table 2. Derivation of accuracy statistics used in model evaluation. [o = observed daily discharge; s = simulated daily discharge; $\overline{o}$ = mean daily observed discharge; $\overline{s}$ = mean daily simulated discharge; N = number of simultaneous observation/simulation daily pairs]

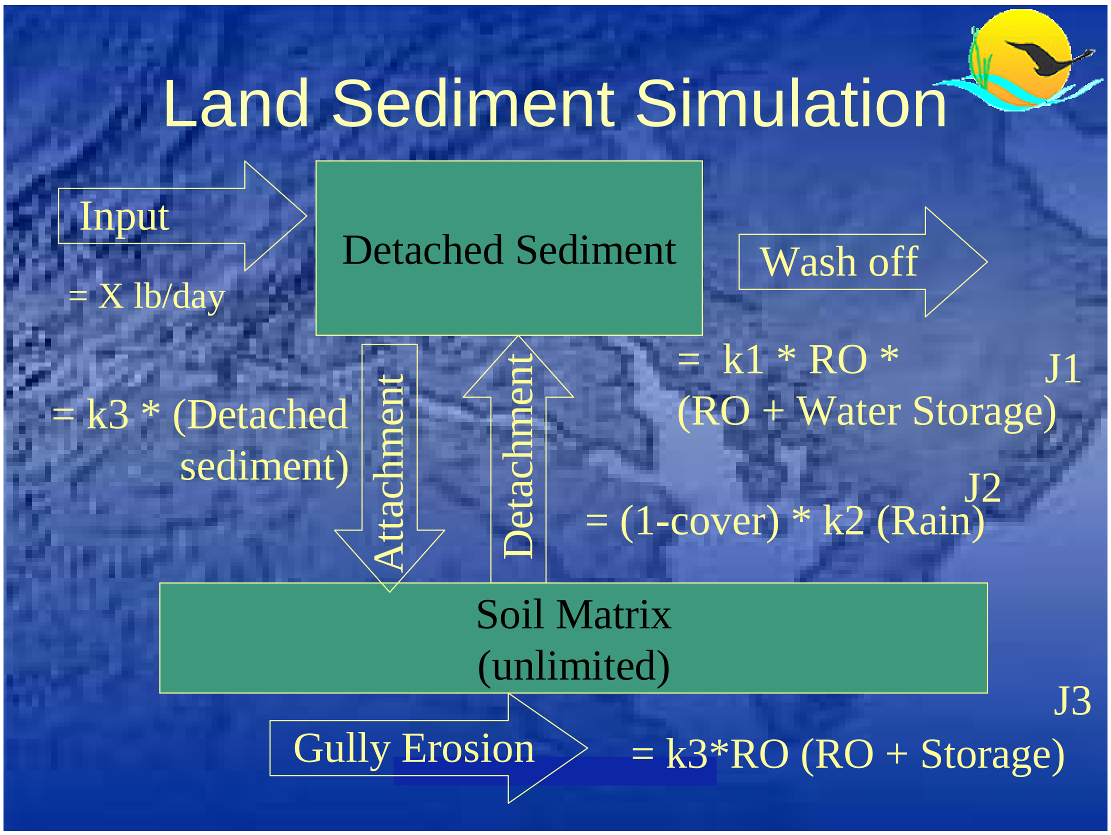
Statistic	Name	Derivation
$\overline{x}$	Mean	$\overline{o} = \frac{1}{N}\sum_{i=1}^{N} o_i \quad \overline{s} = \frac{1}{N}\sum_{i=1}^{N} s_i$
σ^2	Variance	$\sigma_o^2 = \frac{1}{N-1}\sum_{i=1}^{N}(o_i - \overline{o})^2 \qquad \sigma_s^2 = \frac{1}{N-1}\sum_{i=1}^{N}(s_i - \overline{s})^2$
σ_ε^2	Error Variance	$\sigma_\varepsilon^2 = \frac{1}{N-1}\sum_{i=1}^{N}(s_i - o_i)^2$
ε_s	Relative Standard Error	$\varepsilon_s = \frac{\sigma_\varepsilon^2}{\sigma_o^2}$
E	Nash-Sutcliffe Model Efficiency	$E = 1 - \varepsilon_s$
Bias	Relative Bias	$r_b = \frac{1}{\overline{o}}\left[\frac{1}{N}\sum_{i=1}^{N}\left(s_i - o_i\right)\right]$
Wstat	Winter Bias Statistic	As above, by season (Winter)
Sstat	Summer Bias Statistic	As above, by season (Summer)
Bstat	Baseflow Statistic	$Bstat = 1 - \frac{\text{baseflow}/\text{total flow (observed)}}{\text{baseflow}/\text{total flow (simulated)}}$
QaveRI	Average Quickflow Recession Index Statistic	$QaveRI = 1 - \frac{mean\left(\text{simulated quickflow recession index}\right)}{mean\left(\text{observed quickflow recession index}\right)}$
BaveRI	Average Baseflow Recession Index Statistic	$BaveRI = 1 - \frac{mean\left(\text{simulated baseflow recession index}\right)}{mean\left(\text{observed baseflow recession index}\right)}$
Pbias	Peak Bias	As above for relative bias, using observed and simulated storm peaks
Vpbias	Volume of Peak Bias	As above for relative bias, using volumes of simulated storm peaks


April 1 Bias
120
100
80
60
40
20
0
-103%
-83%
-63%
-43%
-23%
-3%
18%
38%
58%
78%
98%


Iterative Calibration Bias
120
100
80
60
40
20
0
-103%
-83%
-63%
-43%
-23%
-3%
18%
38%
58%
78%
98%

Sediment Calibration
Initial steps were made to develop software and procedures for sediment calibration. Data from USGS databases were compiled. Jing Wu (CBP) made a number of improvements and additions to the statistics that we will use for calibration, including summaries of edge-of-field and edge-of-stream loads.

The basic conceptual model for HSPF simulation of sediment washoff from the land is shown below. Sediment is detached from the matrix through rainfall impact and may re-attach through time. The detached material, including any other inputs, forms a store of transportable detached sediment that washes off during events with surface runoff. This material constitutes the edge-of-field load, may be attenuated by a specified amount before reaching the edge of stream, and is then transported within river reaches as cohesive or non-cohesive material, with additional deposition and/or scour possible within the reach.



The steps necessary to begin sediment calibration are as follows:

1) NRI estimates for edge-of-field loads by County and land-use type are being compiled in a form we can easily compare with simulated edge-of-field loads.

2) Final hydrology calibration parameters will be obtained using iterative objective calibration, once final land use becomes available and other small corrections (F-tables, reservoirs, etc.) are made.

3) The delivery factors (attenuating edge-of-stream loads) need to be determined spatially.

These steps will be completed over the next quarter.

Plans for Next Quarter

The next quarter will focus on completing sediment calibration. In addition, we will begin assembling observational databases for nutrient calibration.

References

Bicknell, B.R., Imhoff, J.C., Kittle, J.L., Jr., and Donigian, A.S., Jr., 1996, Hydrological Simulation Program-FORTRAN user's manual for Release 11: U.S. Environmental Protection Agency.